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Research Paper

Comparative Analysis of P&O and IC MPPT Techniques under Different Atmospheric Conditions

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Abstract: Solar photovoltaic (PV) systems have rapidly become a significant energy supply in the world over the last two decades. PV energy has demonstrated its importance among the other renewable energy sources concerning the greenhouse gas emissions and several negative impacts of other energy sources. According to solar irradiation and ambient temperature, the output power of the PV panels can be of various values. Therefore, different types of power electronics strategies have been used to extract the maximum energy from the PV panels. Maximum Power Point Tracking (MPPT) strategy is the most used technique for PV systems. In this study, the comparative analysis of Perturb and Observe (P&O) and Incremental Conduction (IC) MPPT techniques are performed under different atmospheric conditions. The performance of the P&O and IC techniques is observed in the simulation environment using Matlab/Simulink model. Based on the tracking time and the output fluctuation of the PV system, two MPPT techniques are compared. The advantages, disadvantages, and limitations are discussed. The proposed PV system can properly track the maximum power point for both MPPT techniques. The IC technique offers a reduction of the steady-state oscillation and has a better response time to find the maximum power point at the start of the simulation.

Keywords: Solar energy, photovoltaic systems, MPPT, irradiation, temperature

1. Introduction

In recent decades, renewable energy sources have grown significantly in the world to meet the enormous energy demand. The sun supplies more than enough energy to cover the world's energy requirements, and unlike fossil fuels, it will never run out. The main constraint of solar power as a renewable energy source is our inability to convert it into electricity in an efficient and cost-effective manner. Photovoltaic (PV) energy, which is one of the leading renewable energy sources, is based on the principle of converting photons directly from sunlight into electrical energy by the use of the photovoltaic effect [1-4].

PV energy can meet the electricity needs of many applications such as stand-alone devices, lighting for roadways, satellites, transportation, and water pumps for agricultural purposes. Different techniques are used to harvest the maximum power from the sun energy. Solar radiation, ambient temperature, and solar cell temperature affect the value of the maximum power generation in the PV panel [5-7]. Maximum Power Point Tracking (MPPT) technique is used to get the maximum available power from the PV panel as conditions vary [8,9]. There have been proposed many MPPT techniques that are used in solar charge controllers for tracking the maximum power point [10].

In this study, Perturb and Observe (P&O) and Incremental Conduction (IC) MPPT techniques have been selected for comparison under different atmospheric conditions to harvest the maximum power from the PV panel using Matlab/Simulink model.

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2. Methods

The characteristic of the PV panel is nonlinear and its efficiency depends on the irradiance level and ambient temperature. The main principle of MPPT is to generate the most available power of the PV panel by operating it at the most efficient voltage. At the varied solar radiations and ambient temperatures, the PV panel delivers different DC power to the load. According to the applied MPPT technique, the output of the PV panel is checked, and then the best power that the PV panel can deliver to charge the battery or to a DC load is determined. MPPT techniques are most effective under cloudy or hazy days at cold temperatures.

In power electronics, MPPT techniques are used in DC-DC converters for the solar charge controller. Depending on the system design, MPPT technique can be applied to the boost and buck converter. DC output of the PV panel voltage can be increased or decreased by changing the duty ratio of the MOSFET in DC-DC converter. The block diagram of a PV system with MPPT controller is shown in Figure 1.

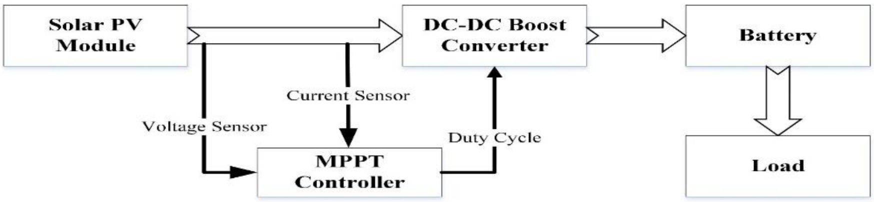

Figure 1. Block diagram of a PV system with MPPT controller

2.1 Perturb and Observe (P&O) Technique

Due to its simple structure, P&O is the most commonly used MPPT technique for tracking maximum power point. This method works by perturbing the PV panel output voltage regularly and comparing the PV panel output power to the earlier state.

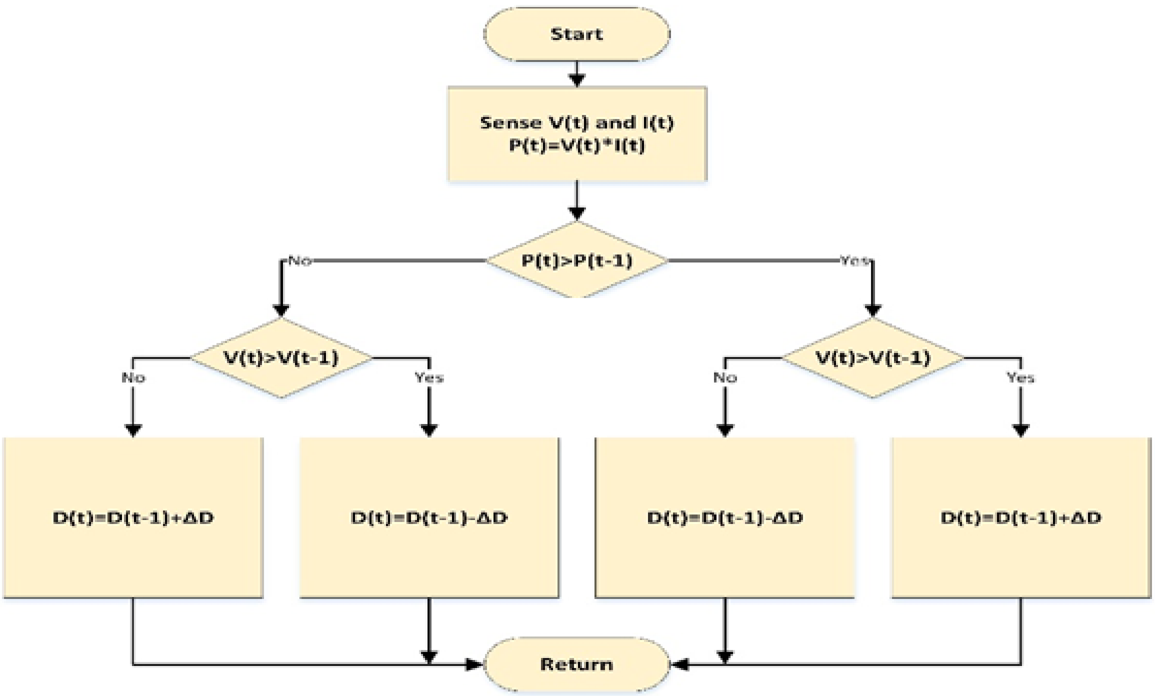

Figure 2. Flowchart of IC MPPT technique

The operating point of the PV panel is moved toward the maximum power point periodically by increasing or decreasing the PV panel voltage. According to the flowchart as shown in Figure 2, if the PV power increases with the panel operating voltage change, the operating point is moved in that direction; otherwise, it is moved in the opposite direction. The oscillation around a maximum power point and decrease in efficiency in case of rapidly changing atmospheric conditions are the major drawbacks of the P&O technique [11,12].

2.2 Incremental Conductance Technique

The IC technique is one of the most used MPPT approaches because of its high tracking accuracy and flexibility to quickly changing environmental conditions. To keep the maximum power point, this technique gets the slope of the PV panel power characteristics. The maximum power point is tracked by seeking the peak of the PV panel power using the IC technique, which detects the slope of the P–V curve. At the maximum power point, the slope of the PV panel power curve will be zero; it will be positive for the left side of the peak point and negative for the right side of the peak point. According to the flowchart as indicated in Figure 3, if the derivative of PV panel power to PV panel voltage is zero, no change will be made. On the other hand, if it is negative the PV panel voltage should be decreased, otherwise, it should be increased [13,14].

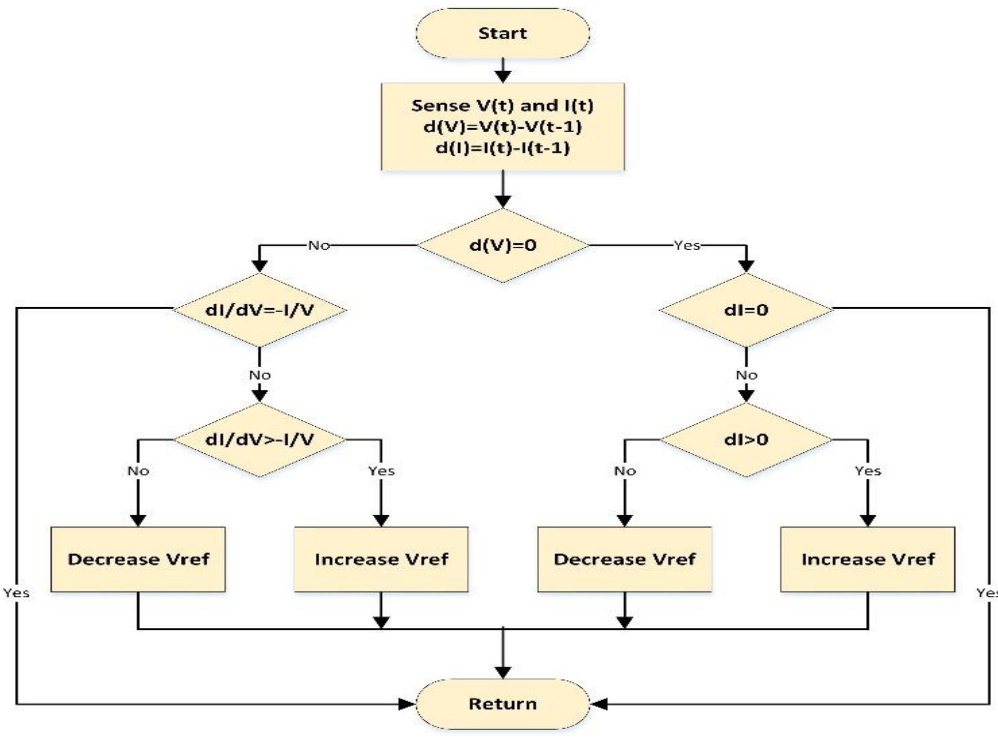

Figure 3. Flowchart of IC MPPT technique

The following equations are given to understand the IC technique. As indicated in (1)–(3), the location of the PV panel operating point in the P–V curve can be determined based on the relationship between the instantaneous conductance and the incremental conductance. (1) denotes that the PV panel works at the maximum power point, while (2) and (3) denote that the PV panel works on the left and right sides of the maximum power point respectively. If the PV panel operates on maximum power point, the derivative of PV panel power to PV panel voltage should be zero.

$$\frac{dP}{dV} = 0 \tag{1}$$

If the PV panel operates on the left side of the maximum power point, the slope of the PV panel power curve is positive and the PV panel voltage should be increased.

$$\frac{dP}{dV} > 0 \; or \frac{dI}{dV} > -\frac{I}{V} \tag{2}$$

If the PV panel operates on the right side of the maximum power point, the slope of the PV panel power curve is negative and the PV panel voltage should be decreased.

$$\frac{dP}{dV} < 0 \; or \frac{dI}{dV} < -\frac{I}{V} \tag{3}$$

2.3 Boost Converter Design

A boost converter is used to increase the input voltage level to higher levels. There are continuous and discontinuous modes for the boost converter during the switching operation. A capacitor and an inductor are employed while the boost converter steps up the DC voltage source. Circuit parameters of the boost converter must be properly selected to obtain optimal efficiency [15].

The minimum values of the inductor L_{min} and capacitor C_{min} can be determined by using the equations that are provided below, where ΔD is duty cycle of the MOSFET, R is load resistance, f is switching frequency, ΔV is capacitor voltage ripple, and Δ_{iL} is inductor current ripple. The boost converter parameters of the Matlab/Simulink model are listed in Table 1.

$$L_{min} = \frac{\Delta D(1-\Delta D)^2 R}{2f} \tag{4}$$

$$C_{min} = \frac{\Delta D}{R \Delta V f} \tag{5}$$

Table 1. Boost converter parameters

Parameters	Values
Input voltage (V)	30
Output voltage (V)	60
Load resistance (Ω)	10
Inductance (mH)	1
Capacitance (μF)	100
Switching frequency (kHz)	25
Duty cycle	0.5
Inductor current ripple Δ_{iL}	%10
Capacitor voltage ripple ΔV	%3

3. Results and Discussion

For the comparative study, P&O and IC MPPT techniques are simulated using Matlab/Simulink environment. A 1 kW PV array and DC-DC boost converter with MPPT controller are used to simulate the relevant MPPT techniques as shown in Figure 4. The PV array parameters used in the Matlab/Simulink model are listed in Table 2. By increasing or decreasing the duty ratio of the MOSFET the maximum power point is determined. The duty ratio of the MOSFET is calculated according to the MPPT techniques applied in the Matlab/Simulink model.

Table 2. PV array parameters

Parameters	Values
Series-connected modules per string	1
Parallel strings	4
Maximum power (W)	250
Cells per module (Ncell)	60
Open circuit voltage Voc (V)	37.3
Short-circuit current Isc (A)	8.66
Voltage at maximum power point Vmp (V)	30.7
Current at maximum power point Imp (A)	8.15
Temperature coefficient of Voc (%/deg.C)	-0.36901
Temperature coefficient of Isc (%/deg.C)	0.086998

As illustrated in Figure 5 and Figure 6, the simulations have been conducted under various irradiance at constant temperature and various temperatures at constant irradiance respectively. Changes in solar irradiance and cell temperature affect the output power directly. While the output power from the PV panel is directly proportional to solar irradiance intensity, the obtained efficiency is inversely related to the ambient temperature. The simulation results of P&O and IC MPPT techniques for the variation of irradiance at constant temperature and the variation of temperature at constant irradiance are given in Figure 7, Figure 8, Figure 9, and Figure 10 respectively.

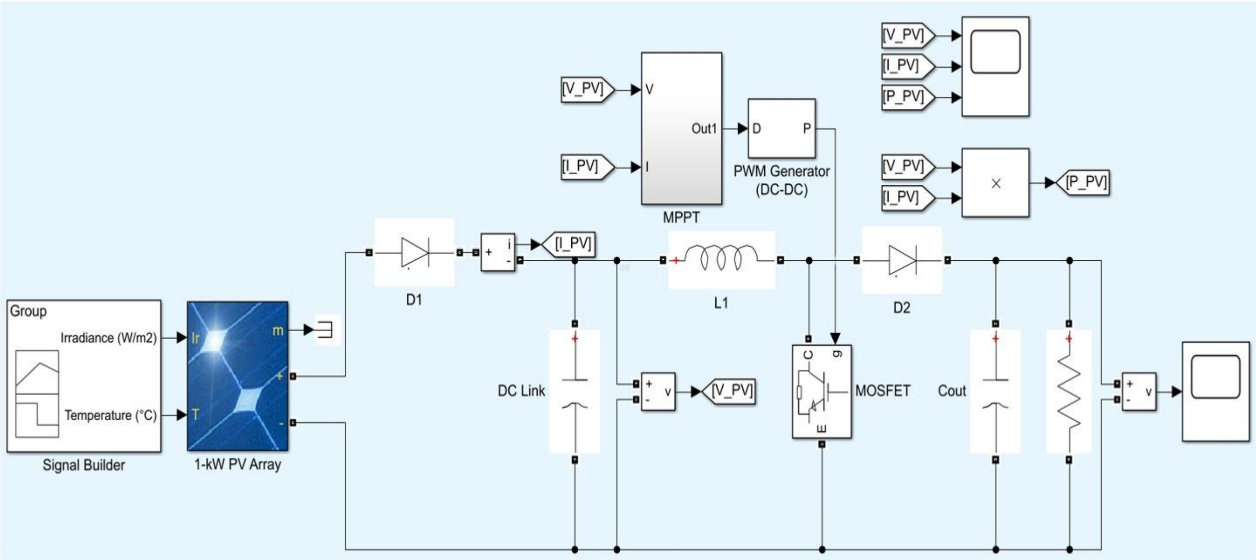

Figure 4. 1 kW PV array and DC-DC boost converter with MPPT controller

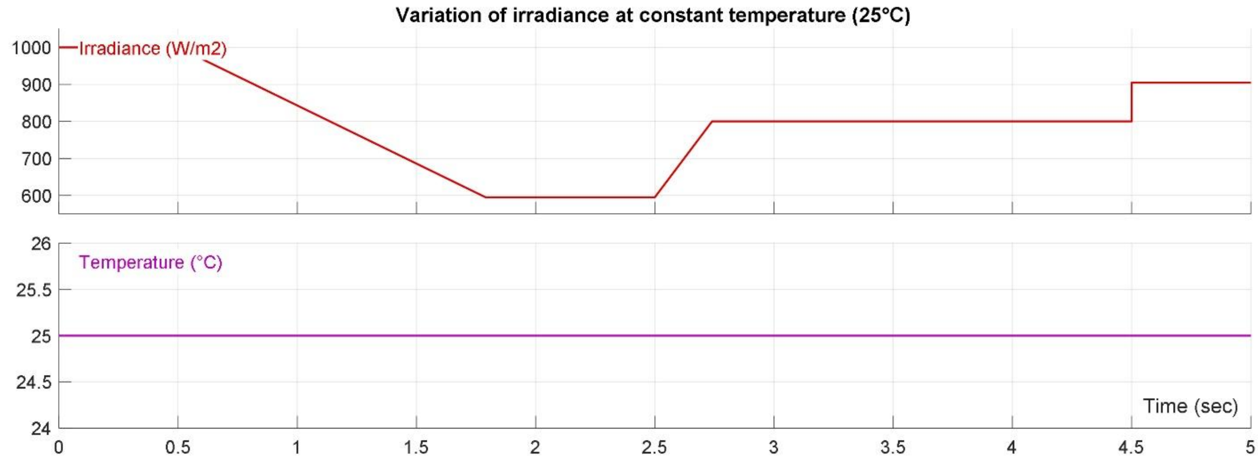

Figure 5. Variation of irradiance at constant temperature

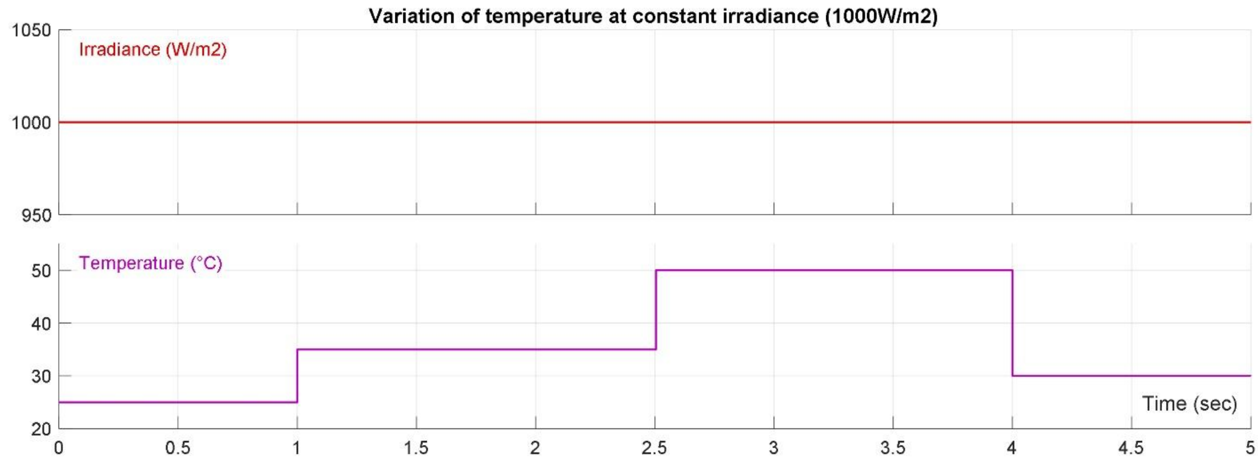

Figure 6. Variation of temperature at constant irradiance

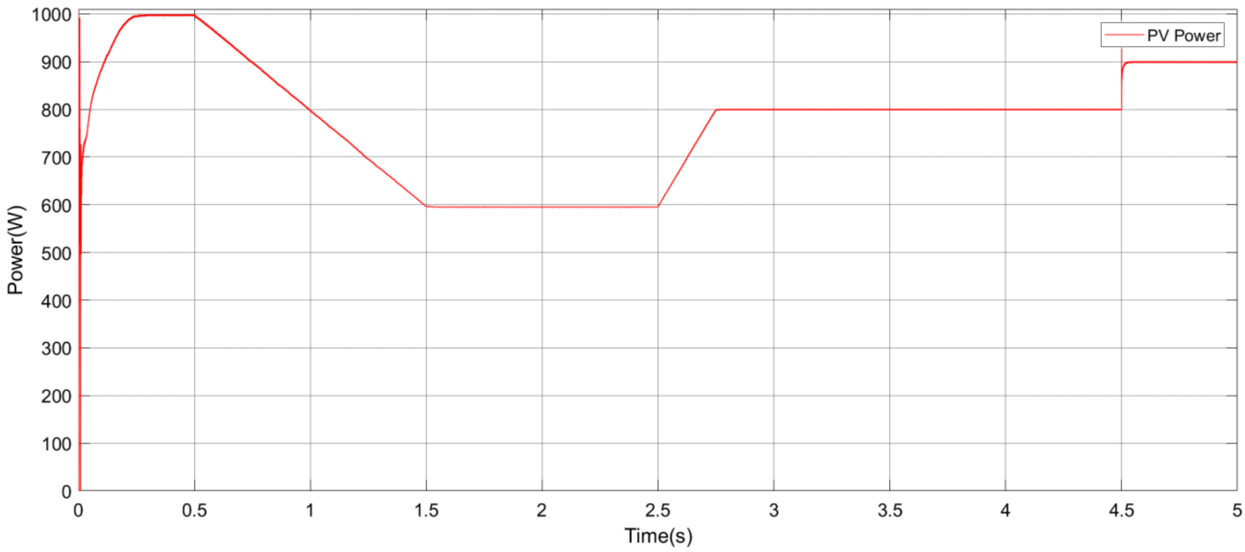

Figure 7. PV panel output power with P&O for different irradiance levels at constant temperature

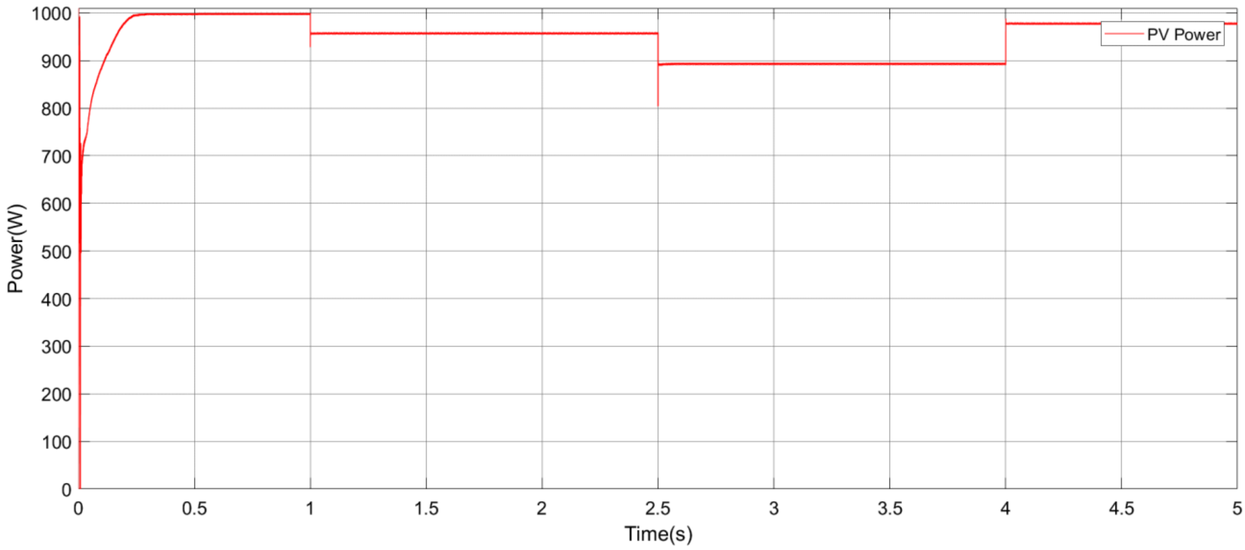

Figure 8. PV panel output power with P&O for different temperature levels at constant irradiance

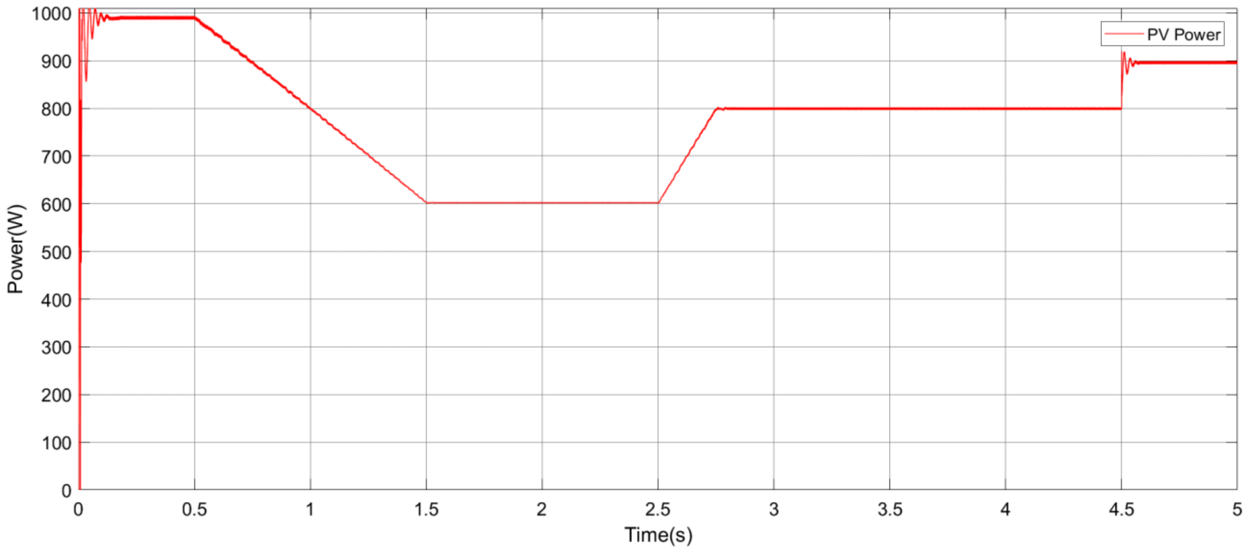

Figure 9. PV panel output power with IC for different irradiance levels at constant temperature

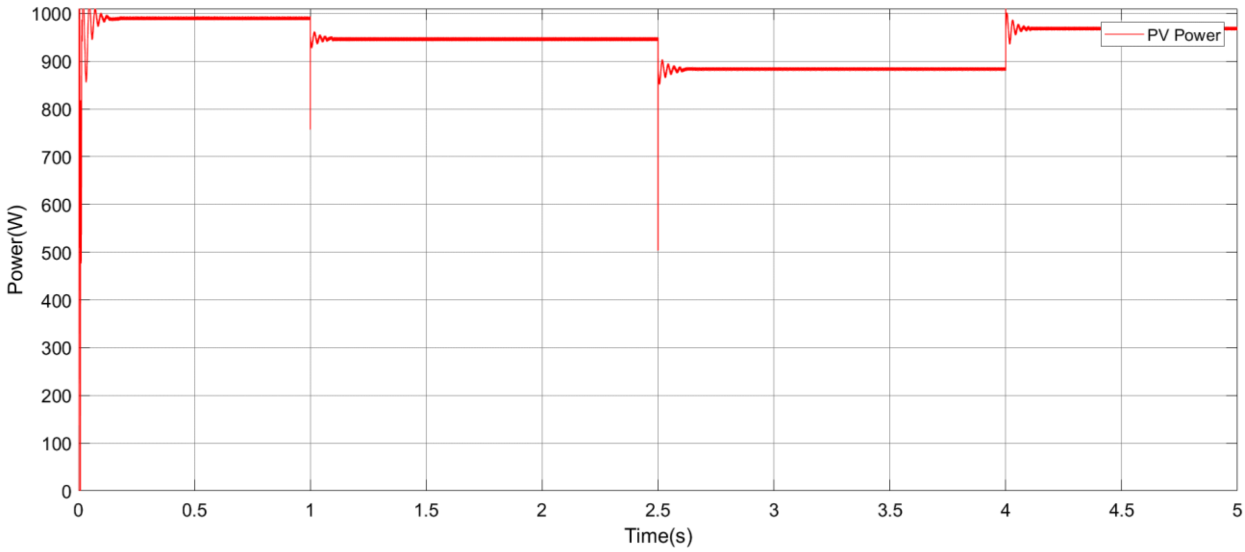

Figure 10. PV panel output power with IC for different temperature levels at constant irradiance

The simulation results of the 1 kW PV array and DC-DC boost converter with MPPT controllers under different atmospheric conditions are compared in terms of response time to reach the maximum power point and tracking performance at the maximum power point. Under two different scenarios, at constant temperature (25°C) and different irradiance levels from 1000W/m^2 to 600W/m^2 then to 900W/m^2, and constant irradiance and different temperature levels from 25°C to 50°C then to 30°C, PV panel output power has been observed. According to the simulation results from the Matlab/Simulink model, both MPPT techniques were successful in detecting and tracking the maximum power point.

With oscillation around the maximum power point, the P&O technique can track the maximum power point. Furthermore, it needs a longer response time to reach the maximum power point during the start-up phase. A larger perturbation step size can be used to solve this problem. However, increasing the step size will lead to the loss of the PV panel power due to the not exact maximum power point tracking. To make the step size smaller will also cause a slower response time for the maximum power point tracking. Therefore a variable perturbation step size can be applied in the P&O technique by modifying the algorithm for better performance.

Compared to the P&O technique, the IC technique offers a reduction of the steady-state oscillation and has a better response time to find the maximum power point at the start of the simulation. The main advantages of the IC technique from the P&O technique are the decreased oscillation in steady-state once the maximum power point is detected and an improved response time which increased the efficiency of the PV panel output power.

4. Conclusions

This paper investigates the performance of P&O and IC MPPT techniques under variable irradiance and variable temperature values. The same standard environmental conditions are applied to compare two MPPT techniques using Matlab/Simulink model. Based on the environmental conditions, the duty cycle of the MOSFET in DC-DC boost converter is increased or decreased to determine the maximum power point according to the applied MPPT technique. As shown in the simulation results, the PV panel output power was able to find and track the maximum power point for both MPPT techniques. The findings show that the IC technique could be preferred to the P&O technique under variable weather conditions to track the maximum power point with lower oscillation in steady-state and better response time which contributes to a high stability operation in PV systems.

Competing interests

The author declares no competing interests.

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